# VARIATIONS IN THE SIZE OF CHROMOSOMES.

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OUTLINE OF CONTENTS.



## I. INTRODUCTORY.

From the time that the importance of germ cell chromosomes was first realized, the mass of investigation on this subject has dealt with the development of the chromosomes. Practically nothing on a comparison of chromosomes of the same species has been published. Therefore these results are given that they may throw some light on the behavior of chromosomes.

The observations in this paper, although somewhat limited, suggest interesting theoretical considerations.

Further investigations are being made by the author to test these ideas.

## II. MATERIAL.

All of the material is of the species *Schistocerca americana*, with the exception of one specimen which is *S. alutacea*. A brief description of the material follows.

*Young Nymphs.*—Out of a number of nymphs, collected at the same time and place near the Kansas University campus, nine were taken at random. These were probably of the same age, for they were of approximately equal size, ranging from 12 to 14 mm. in length.

*Older Nymphs.*—Two of them, one 26 mm. long, wing stubs 6 mm.; the other 33 mm. long, wing stubs 9 mm. Both were collected by W. R. B. Robertson in Dickinson Co., Kansas.

*Adults.*—Two were furnished by Mr. Robertson from the locality mentioned above. Three were furnished by the Kansas University Zoölogy Department, two of them being *S. americana* and the other *S. alutacea*. The average measurement of dried adult specimens was 44 mm. exclusive of wings.

All material was fixed with Flemming and stained with Heidenhain's iron hæmatoxylin.

## III. Observations.

### 1. *Comparison of Chromosomes.*

(*a*) *Chromosomes of Nymphs Compared with Those of Adults.*—The greater size of the chromosomes of adults as compared with those of nymphs is most easily seen in the first spermatocyte stages, as there the chromosomes are the largest of any period in their history. Great contrast in the size of chromosomes appears in both metaphase and anaphase, provided the nymphs are young enough. The nymphs, showing the greatest contrast were less than one third grown.

In first spermatocyte metaphase the chromosomes of young nymphs occur more in the spherical or short rod form than as rings or twisted rods which in adults are common. Large chromosomes are usually doubled or coiled and as there are not so many large ones in the nymph cells naturally the number of these complicated forms is smaller.

A large number of drawings were made as carefully as possible with a camera lucida. A few of these were selected in illustrating this paper. They are all typical of the material studied.

The twelve chromosomes within a cell were numbered according to their size. In almost every case the corresponding chromosomes of adult cells were larger than those of young nymph cells. The exceptions to this, although few, occurred among the chromosomes of smaller size (see Plate I., Figs. 1 and 2, 3 and 4, 5 and 6, 15 and 16). In some instances there was great contrast in size (see Plate II., Figs. 25 to 32).

In first spermatocyte anaphase the same comparison holds

good with the exception of the chromosome form. The V- or U-shaped chromosomes of young nymphs are shorter and thicker than those of adults (see Figs. 33 to 47, Plate II.).

In the second spermatocyte metaphase there is a repetition of the size differences discussed in connection with the first spermatocyte (see Figs. 48 to 55, Plate III.). In connection with this it should be stated that almost invariably the cells of the young nymphs were smaller than those of adults.

(*b*) *Comparison of Chromosomes of Different Cells of the Same Individual.*—One of the most interesting conditions appeared in different cells of the same individual. Chromosomes which correspond as the number ones of the different cells show in many cases variations in size (compare corresponding chromosomes of the groups in: Figs. 1, 3, 6, 8, 9, 11, 14, 16; Figs. 2, 4, 5, 7, 10; Figs. 12, 13; Figs. 17, 19, 22, 24, 25, 27, 30, 32; Figs. 18, 23; Figs. 20, 21; Figs. 26, 28, 29, 31; Figs. 56, 57; Figs. 58, 59; Figs. 60, 61, 62, 63). In some instances this difference in size is very striking (see ones in Figs. 5 and 7; nines in Figs. 12 and 13; ones, twos, and threes in Figs. 22 and 24; and many others which are evident by a comparison of the figures).

A great number of cells were studied to find whether this size variation was exceptional. The variation was not unusual, but very common.

The first spermatocyte anaphase presented like differences in size (see Figs. 33, 35, 37, 39, 41, 43, 47; Figs. 34, 38, 40, 42).

Chromosmes in the second spermatocyte metaphase show similar variations (Figs. 48, 50, 55, 49, 51, 54).

The second spermatocyte anaphase chromosomes are just as variable (Figs. 64, 65, 66, 67).

There is no doubt that corresponding chromosomes of the same individual show a tendency to vary in size. This tendency becomes more marked in certain cells.

### 2. *Causes of Chromosome Size Variation.*

(*a*) *Unequal Growth.*—During early prophase of the first spermatocyte it is well known that the chromosomes appear as groups of granules, which may be more or less clearly distinguished from each other.

One slide which had most of the stain removed contained a number of cells of the early prophase with only one group of granules showing distinctly. The other granules were either very faint or else did not show at all. The granules of this group varied in size and number and in many cases were in the process of division (Figs. 69, 70, and 75 to 80). When the cells grew older, as could be determined by the increase in size of the cell and the appearance of the spiremes of the other chromosomes, the granules of this group began to come closer together and finally fuse (see Figs. 71 to 74 and 82).

The body produced by this fusion is unquestionably a chromosome because it is made up of granules which have the power of division. It is not the accessory chromosome for the accessory is present in practically every cell containing it.

The chromosome appearing in this series of observations seems to vary in size as commonly found among corresponding chromosomes of the same individuals (described above) (compare Figs. 73 and 74).

The number of granules in each group where no fusion had commenced was as follows: 7, 9, 9, 14, 9, 10, 8, 9, 11, 10—between 9 and 10 seemed to be the average. The fact that some granules had not divided could account to a certain extent for the differences in number, but not in every case, as Fig. 70, in which but one granule is undivided would give but 10 granules if this were divided. An examination of the other groups will show like discrepancies. Therefore the number of granules varies independently of their condition of division.

The variation in the size of the granules in cases where fusion had not occurred, was considerable. Even where all of the granules had divided they varied in size (see Fig. 75, as well as many of the other groups figured). This is true whether we compare granules of the same cell or of different cells (see Figs. following 68 and 75).

(*b*) *Unequal Division.*—In some of the lateral views of the first spermatocyte a few small chromosomes were found dividing unequally (Figs. 85 to 91). One cell contained two chromosomes dividing unequally (Fig. 88). Small chromosomes were found dividing unequally in the second spermatocyte (Figs. 83 and 84).

There is no question then that unequal division does sometimes occur in chromosomes.

## IV. Discussion.

### 1. *Chromosome Variations and Their Causes.*

The difference in size of chromosomes of nymphs as compared to adults depends upon the age of the nymphs. It also bears a direct relation to the size of the cells, the smaller cells of nymphs containing the smaller chromosomes.

Cells of young nymphs are dividing more rapidly than are those of adults, for that reason they probably have not the chance to grow so large. In addition to this the body cells in young animals undoubtedly develop at the expense of the germ cells because it is more important that the body organs become established before the germ cells are brought into activity. Then when the body has almost reached its growth the germ cells get their share of nutrition and become larger as do the chromosomes.

A study of the growth stages of a corresponding chromosome, in the same individual shown in Figs. 68 to 82, has demonstrated that the number and size of the granules differ. Either is sufficient cause for a variation in size of corresponding chromosomes.

Unequal division likewise produces unequal chromosomes.

These two facts lead us to expect unequal corresponding chromosomes in the same animal. A careful study proves that this is of common occurrence, regardless of the species concerned.

### 2. *The Rôle of Chromosome Variations in Heredity.*

*Theoretical.*—It has been believed for a long time that the chromosomes of the germ cells play the most important part in heredity. Their individuality seems to be established as the result of the work of many investigators. The picture which we now have of each individual germ cell chromosome is a body which is able to transmit a certain group of characters in the formation of a new organism. Each corresponding chromosome in different cells would represent the same group of characters while the different chromosomes of each cell would represent different groups of characters.

We have the right to assume that some chromosomes within the cell have greater influence in determining the characteristics of a new individual, otherwise they would all have equal power in this respect, which is inconceivable. Especially is this so when we see the great difference in the size of chromosomes within the same cell because there must be some purpose in this if the chromosomes are so important.

Naturally the larger chromosomes would represent larger groups of characters or else power to make the characters, which they determine, more prominent.

By a variation then in size of any one chromosome either the number or the intensity of the characters, which it represented, would be varied. If the chromosome is increased, its influence in the determination of the characteristics of the offspring would also be increased.

Knowing that the offspring from the same parents show considerable variation in their characteristics and having found that corresponding chromosomes of the same animal vary in size it seems probable that we have in this the cause of continuous variation.

According to this theory if an immature animal were mated with one of maturity, on account of the smaller size of its germ cell chromosomes (shown in the first portion of this paper) the immature germ cell would be overshadowed by the mature germ cell in the determination of the characteristics of the resulting offspring. In many cases this seems to be true though it is difficult to obtain trustworthy data.

## V. Conclusion.

1. Germ cell chromosomes of very young nymphs are smaller than those of adults; this difference bears a direct relationship to the size of the germ cells.

2. As a result of either unequal growth or unequal division, corresponding chromosomes of different cells within the same individual vary in size.

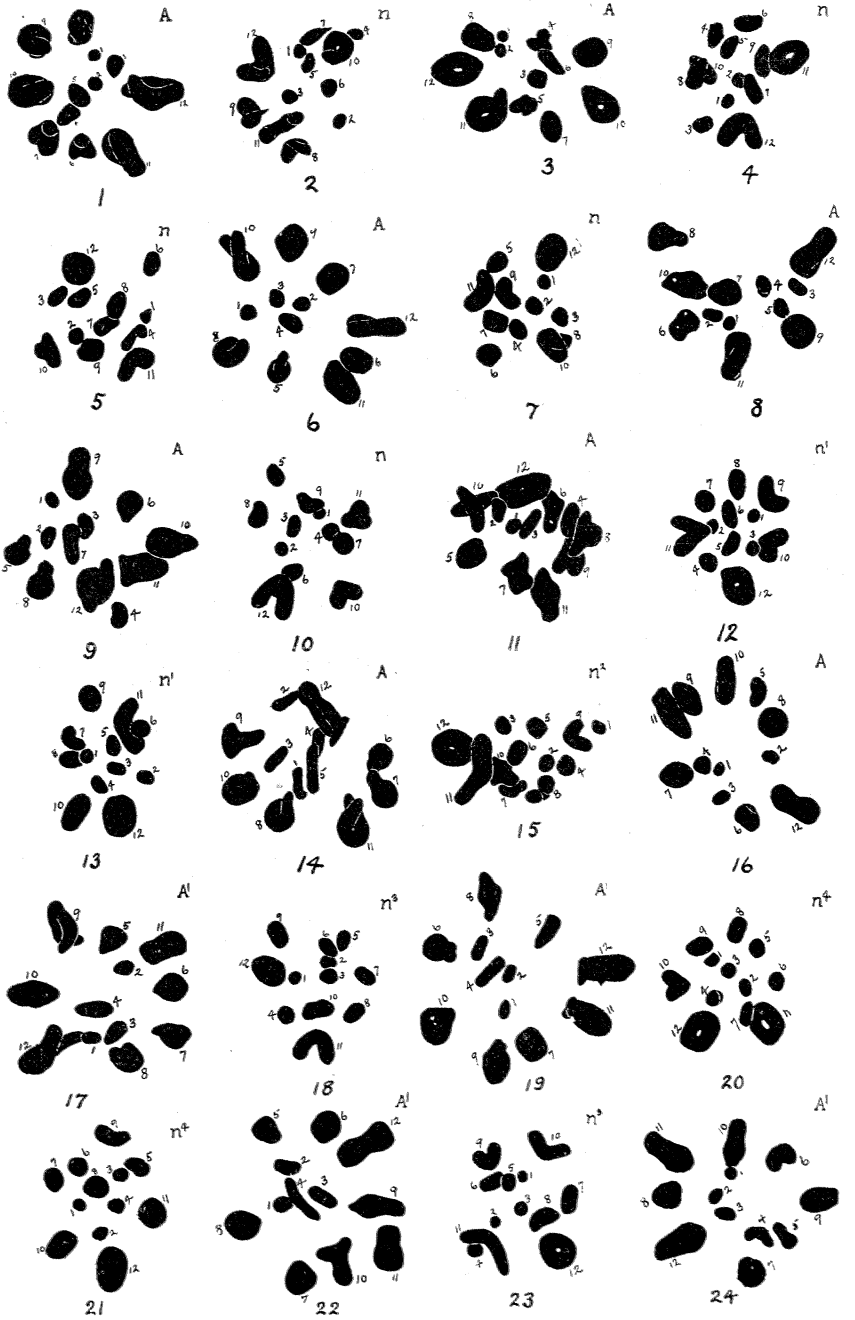
3. The theory suggested by the observations in this paper is that the variation in the size of corresponding chromosomes of germ cells is the cause of continuous variation among animals.[1]

[1] The author is indebted to Dr. C. E. McClung for criticism.

## PLATE I.

FIGS. 1 to 24 inclusive. Polar view of chromosomes in first spermatocyte metaphase. Drawings of this and the succeeding plates made with the aid of a camera lucida.

Figs. marked *A* are from adults, *A* and $A^1$ being from different animals. Figs. marked *n* are from young nymphs. *n*, $n^1$, $n^2$, $n^3$, $n^4$ being from different animals. Chromosomes are numbered according to their size in the cell beginning with the smallest. The difference in size between nymph and adult cell chromosomes is very striking. A comparison of corresponding chromosomes of different cells of the same animal shows the variation in size mentioned in this paper.


A
n
A
n
1
2
3
4
n
A
n
A
5
6
7
8
A
n
A
n'
9
10
11
12
n'
A
n²
A
13
14
15
16
A'
n³
A'
n⁴
17
18
19
20
n⁴
A'
n³
A'
21
22
23
24

## PLATE II.

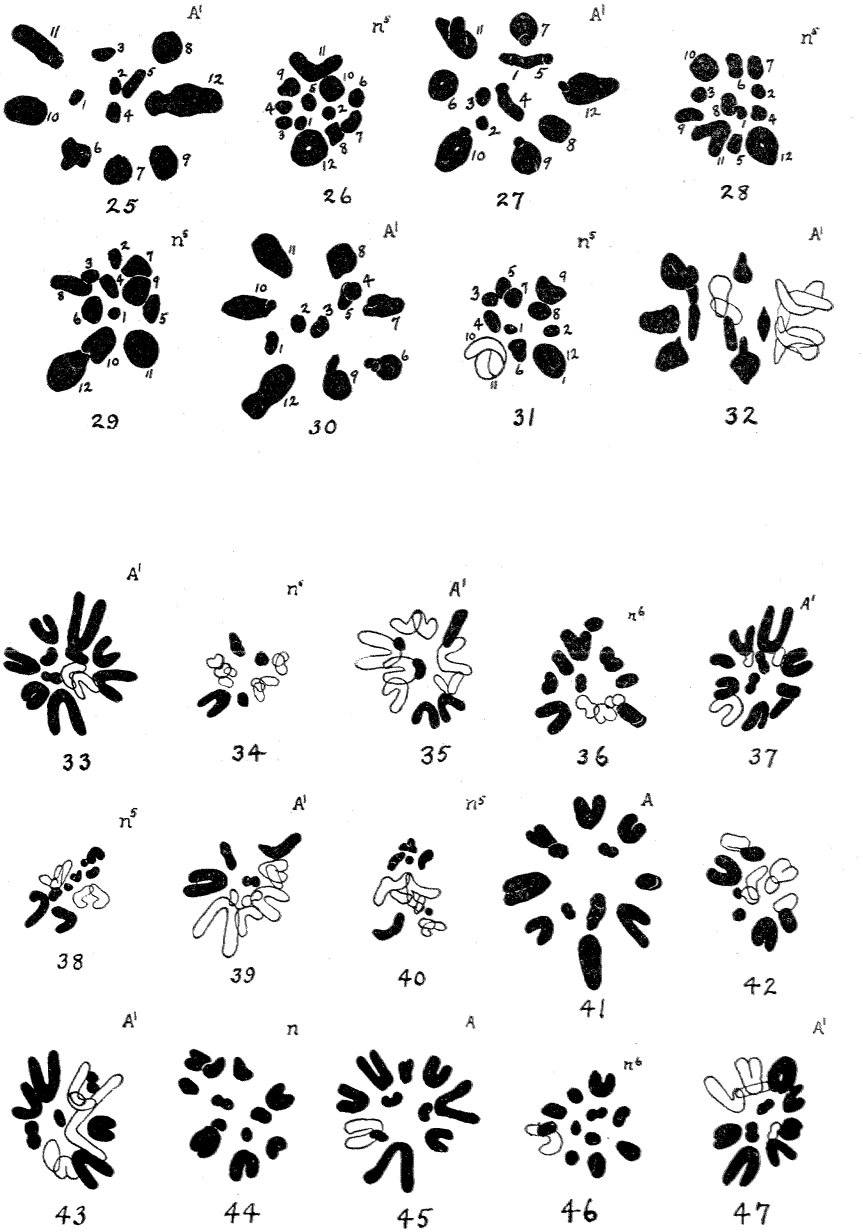
FIGS. 25 to 32 inclusive. Polar views of chromosomes in first spermatocyte metaphase.

FIGS. 33 to 47 inclusive. Polar views of first spermatocyte anaphase.

Scheme of lettering and numbering as in Plate I., $n^5$ and $n^6$ being from animals not represented in Plate I.

The greater size of the chromosomes of adults more pronounced than in Plate I.

In both metaphase and anaphase the variation in size, between corresponding chromosomes of the same animal, is evident.


A¹
n⁵
n⁶
A
n
25
26
27
28
29
30
31
32
33
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35
36
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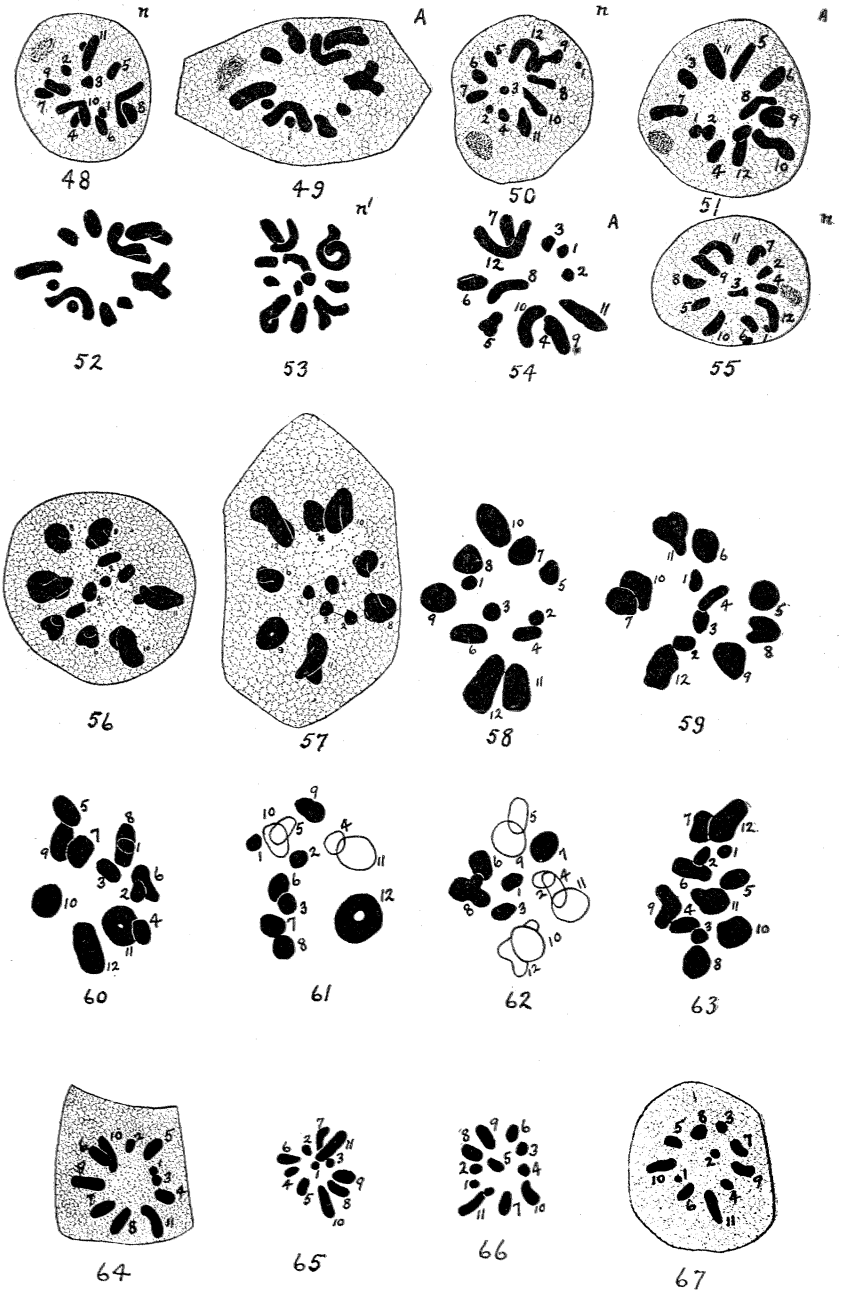
## PLATE III.

FIGS. 56 to 63 inclusive. Polar views of the first spermatocyte metaphase, showing the variation in size of corresponding chromosomes of the same animal. Figs. 56 and 57 are from one animal, Figs. 58 and 59 are from one animal, Figs. 60, 61, 62 and 63 are from one animal.

FIGS. 48 to 55 inclusive. Polar views of the second spermatocyte metaphase. Figs. 48, 50, 53 and 55 are from young nymphs, 48, 50 and 55 being from the same animal. Figs. 49, 51, 52 and 54 are from adults, all but Fig. 52 being from the same animal.

The chromosomes and cells of the adults are larger than those of nymphs as in earlier stages. Corresponding chromosomes of the same animal also vary in size at this stage as well as in the next stage (anaphase) represented by Figs. 64 to 67 from the same animal.

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## PLATE IV.

FIGS. 68 to 74. Stages in the development of a single chromosome (*r*) during first spermatocyte prophase. The stain had been removed from all of the other chromosomes except the accessory.

FIGS. 75 to 82. Granules of the corresponding chromosome from other cells of the same animal.

Fig. 75. All granules divided.

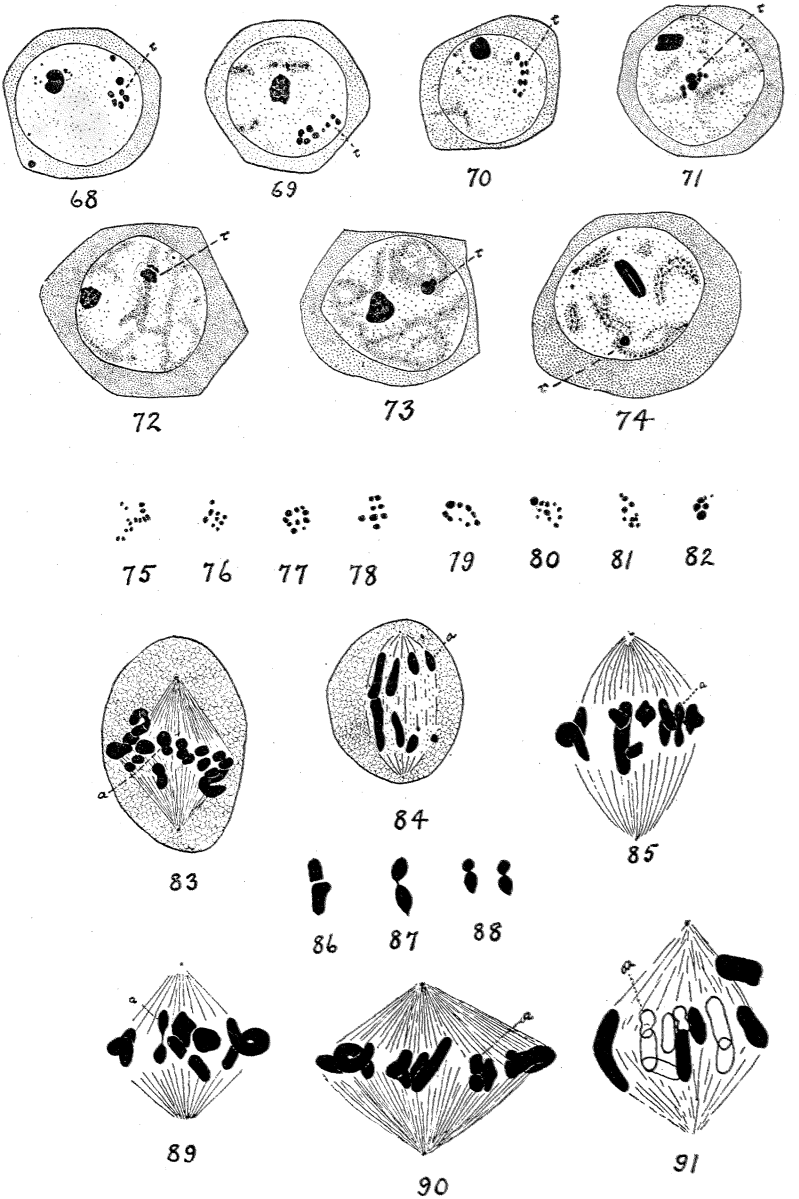
Figs. 71 and 72. Granules in the process of fusion.

The granules vary in size and number at similar stages.

FIGS. 85, 89, 90 and 91. First spermatocytes, showing chromosomes (*a*) dividing unequally.

FIGS. 86, 87 and 88. Other examples from the same stage, those in 88 being from the same cell.

FIGS. 83 and 84. Second spermatocytes, showing chromosomes dividing unequally.

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